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A Decision support system for evaluation of the knowledge sharing crossing boundaries in agri-food value chains

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Abstract

An agri-food value chain (VC) represents a set of activities aimed at delivering highly valuable products to the market. Due to the diversity of actors in the agri-food VCs' accumulated knowledge is typically situated within the boundaries of each entity of the VC. Hence, the question is how to improve knowledge sharing in agri-food VC, or more specifically how can knowledge flow and mobilize among different actors in the VC. To answer this question, we present a decision support system (DSS) for evaluation of knowledge sharing crossing boundaries in agri-food VC. The proposed DSS is developed through two phases: (i) identification of the most common knowledge boundaries by using machine learning and ontology technologies; (ii) transformation of the obtained ontology into a DSS for the evaluation of existing knowledge boundaries. In particular, the developed DSS helps in identifying, evaluating and providing directions for improvement of the knowledge sharing

crossing boundaries in agri-food VC. We apply the DSS to evaluate three real VCs: a tomato VC in Argentina, a Chinese leaf VC in China and a brassica VC in the UK. The comparative analysis across the three varied case studies and their evaluation with the proposed DSS lead to more insights into knowledge-based decisions that a particular VC needs to address to improve its knowledge flow, in particular, to obtain insights in the transparency and interoperability of data and knowledge crossing boundaries in agri-food VCs.

Keywords: Knowledge sharing, knowledge boundaries, decision support system, agricultural value chain

1 Introduction

Knowledge management within organizations and cross-organizational collaboration in value chains (VCs) have been acknowledged as two important parts of crossing the organisation barriers created by knowledge boundaries (Carlile, 2002). The need of crossing organizational boundaries by knowledge sharing comes from the necessity to gain a better understanding of different cultures, disciplines, and management practices, with the aim of developing better and more comprehensive solutions. In particular, cross-organizational collaboration may lead to quicker understanding and grasping of newly developed trends in all kinds of specialised knowledge. However, crossing organizational and knowledge boundaries is a difficult task.

An agri-food VC is formed by a chain of network actors, including different size of producers (responsible for growing food commodities), cooperatives, food processors (responsible for processing, manufacturing and marketing food products), distributors/wholesalers, retailers (responsible for marketing and selling), consumers (end-users who purchase and consume food), and government/non-government organizations (such as research institutions, universities, communities responsible for research, development and knowledge transfer and management among different actors in the agri-food value chain). The diversity of actors in the agri-food value chain naturally leads to varied knowledge which is typically situated within the boundaries of a specific entity of the value chain. Hence, the question that we try to answer is how to perform knowledge sharing crossing boundaries in agri-food value chains, or more specifically how can knowledge flow and mobilize among different actors both vertically and horizontally. Vertically, knowledge flow should be among the whole agricultural value chain, from farm to fork, by freely crossing boundaries between different stages of the value chain. Horizontally, knowledge flow should be able to cross different bodies even at the same stage of the chain but with different level of knowledge. One of the key challenges of knowledge flow, which is a precondition for providing quality decisions, represent the knowledge boundaries whether existing between different domains, different practitioners' groups, or people with different level of knowledge even within the same domain and group, such as between novices and experienced practitioners. Knowledge boundaries exist due to differences in the way we work, share our knowledge, expertise, different organizational culture, or due to the involvement of many actors, for example, farmers, cooperatives, food processors, wholesalers, retailers and consumers (Chen, Liu, & Oderanti, 2017). Typically this knowledge is situated within the boundaries of a specific level of the value chain, hence it is important that

the knowledge assets, which are situated at one level, are linked to another, as represented in Figure 1.

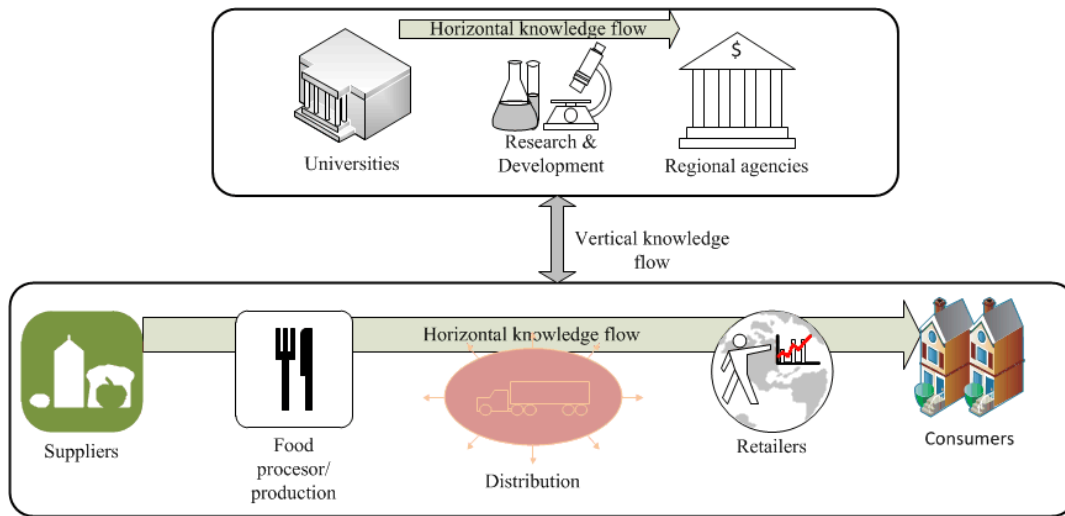


Figure 1 Knowledge sharing in value chain.

This paper reports part of the research work associated with the EU Horizon 2020 project RUC-APS (Enhancing and implementing knowledge based ICT solutions within high Risk and Uncertain Conditions for Agriculture Production Systems, <https://ruc-aps.eu/https://ruc-aps.eu/>), aiming at development of a new decision support system (DSS) for crossing knowledge boundaries in the domain of agricultural value chain.

The main contributions of this paper are threefold. Firstly, we develop a new ontology for knowledge sharing crossing boundaries based on the reported state-of-the-art literature reviews in journal papers published from 2010 – 2018. The obtained ontology helps in identifying the most commonly reported problems and solutions in the field in the last eight years, and aids at grouping the repeated concepts among different actors in the field. Secondly, the ontology is used to define a new DSS and new decision rules which allow considering an extensive hierarchy of attributes for knowledge sharing crossing boundaries. Thirdly, we explored the use of the developed DSS for the evaluation of three value chains investigated in the RUC-APS project, in particular the Chinese leaf value chain in China, tomato value chain in Argentina, and brassica value chain in the United Kingdom. At the end we suggest how to improve the knowledge sharing crossing boundaries in the evaluated VCs.

The rest of this paper is organised as follows. Section 2 states the related work, Section3 explains the used research methodology, Section 4 discusses the data preparation process and Section 5 develops ontology for knowledge boundary concepts. Section 6 discusses the newly developed decision support system. Section 7 presents and evaluates case studies using three

different vegetable value chains in agri-food industry from three different continents. Finally, conclusions are drawn in Section 8.

2 Related work

Many studies have been conducted to find out how knowledge is managed across organizational boundaries (Carlile, 2002), (Carlile, 2004), (Hustad, 2017), (Wilhelm & Dolfmsa, 2018), (Lee, Min, & Lee, 2017), (Nguyen, 2017) . Despite the available knowledge and understanding about the ways of creation of knowledge boundaries in different areas (Swart & Harvey, 2011), the evaluations of knowledge boundaries as well as the influence of knowledge sharing on crossing the knowledge boundaries in agri-food value chains remains still very limited in the literature (Hartwich, Pérez, Ramos, & Soto, 2007). Evaluation of existing knowledge boundaries requires integration of knowledge management into decision support systems, which has been investigated by many scholars resulting in the emergence for development of expert systems and knowledge-based decision support systems (Zarate & Liu, 2016). To propose a suitable DSS based on the available research literature in the period from 2012 – 2018 we apply methods from data science that deal with text analysis.

Data science is concerned with analysis of relevant data with the goal of finding certain patterns of data and their transformation into relevant information rather than focusing on the methodology on how it will achieve it. Therefore there are different methods which may be used, including state-of-the-art methods Latent Semantic Analysis (LSA) and Latent Dirichlet Allocation (LDA). LSA is a method that is used for mining concepts from documents. It uses the mathematical technique of singular value decomposition to define concepts that connect the provided documents. The limitations of LSA include difficulties in the interpretation of the resulting concepts and inability to find direct and indirect association as well as higher-order co-occurrences among terms when using of bag of words model (Abedi, Yeasin, & Zand, 2014). LDA is a well-established method for defining concepts in natural language processing. However some of its limitations include: fixed number of topics which must be known ahead of time, dirichlet topic distribution cannot capture correlations, non-hierarchical, static, bag of words (assumes words are exchangeable, sentence structure is not modelled), unsupervised (sometimes weak supervision is desirable, e.g. in sentiment analysis) (Smolyakov, 2016).

That being said, the proposed methodology in the manuscript, which is based on OntoGen and DEX allows: usage of BOWs, finding hierarchical concepts, defining the number of topics

covered with each of the concepts, interactively finding the most suitable number of sub concepts, visualisation of results, easiness of interpretation of the results etc. OntoGen is indeed state-of-the-art method in which inference and reasoning is based on well-known machine learning technique called Support Vector Machines (Fortuna, Grobelnik, & Mladenić, 2005), (Fortuna, Grobelnik, & Mladenić, 2005a). The proposed ontology is followed with a DSS prepared with a well-known decision making method DEX, implemented in a free of charge, user friendly tool called DEXi. DEX has been used in many areas for developing a qualitative decision making models such as in agriculture (Bohanec, Boshkoska, Prins, & Kok, 2017), (Craheix, in drugi, 2015), environment (Ravnikar, Bohanec, & Muri, 2016), medicine (Bohanec, in drugi, 2018), (Baert, in drugi, 2018) etc. The easiness of usage of both tools leave the user only to deal with the decision of choosing the most suitable documents instead of thinking about the difficulties in the programming implementation of both methods.

The main advantage of our methodology is that it uses state-of-the-art techniques from machine learning and decision analysis, which are implemented in well-known free of charge, user friendly software tools. Hence the user only needs documents in order to use this methodology without being concerned with the additional programming. In addition, both OntoGen and DEXi provide visualization of the results, unlike most of the available methodologies which focus mainly on the mathematical properties of the methods and lack their implementation in user friendly tools.

3 Research methodology

The research methodology follows our proposed three step approach (Mileva Boshkoska, Liu, & Chen, 2018):

- Data preparation step which includes extraction of domain related knowledge;
- Construction of ontology that describes the extracted knowledge;
- Development of a DSS whose structure follows the identified ontology rules.

In our case, the preparation of domain related data includes selection of research articles whose content will be used for extracting knowledge in the form of an ontology. In the second step, an ontology is constructed based on the keywords from the selected articles. The result of this step is a set of rules that determine the relation between certain concepts from the domain

specific knowledge. Finally, the generated DSS that closely matches the identified ontology structure is employed for the evaluation of knowledge sharing crossing boundaries in three agri-food VCs. The details of the used research methodology are schematically presented in Figure 2. In the following, each of the steps is described in detail.

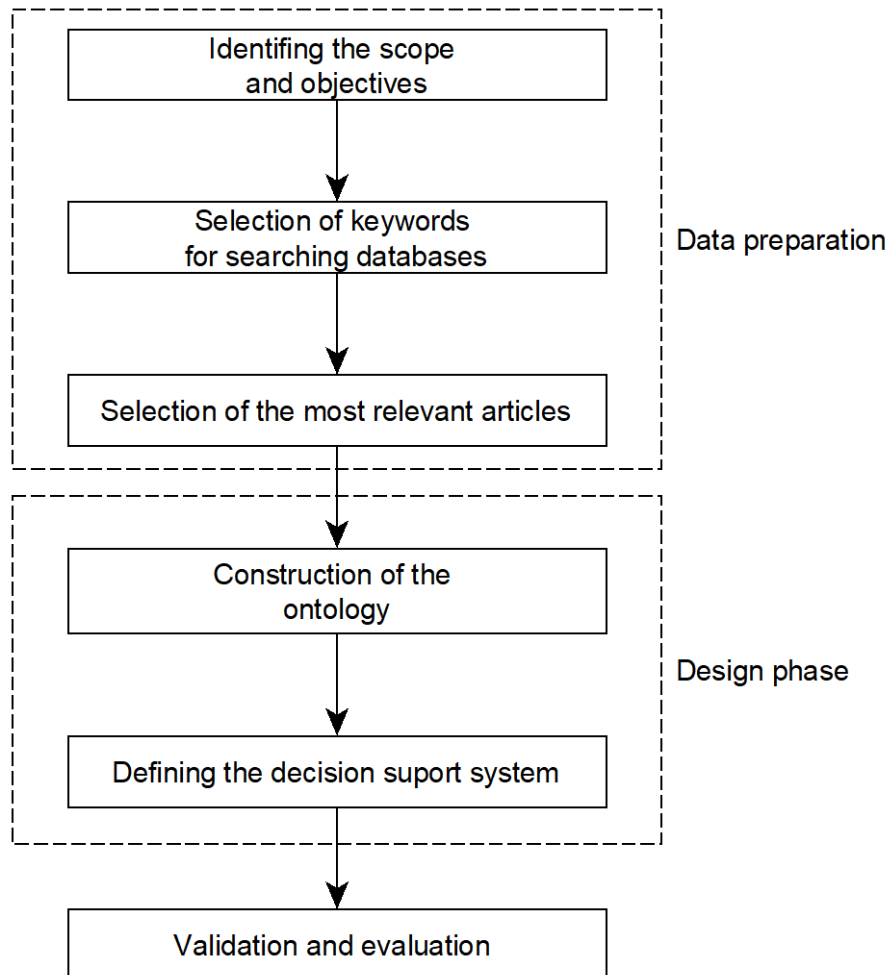


Figure 2 Methodology for preparation of DSS.

4 Data preparation

The data preparation step is crucial for the effectiveness of the overall system. We have firstly identified the key concepts in bridging the knowledge boundaries. These concepts were employed as keywords for searching the Web of Science (WoS) database for extracting papers that deal with the topics of interest. In WoS we searched the *Title*, *Abstract* and *Author keywords* fields within a record in order to obtain the required papers. The resulting set of papers was

pruned by removing duplicated articles, and articles that are out of interest (for example conference articles, short articles, articles published before a certain year, etc).

In the process of *identification of the scope and research objectives* we formulate two research directions. The first one is to develop a DSS model for evaluation of existing knowledge sharing practices, as described in the currently available research articles, based on an ontology describing the current trends in the knowledge sharing crossing boundaries field. The second one is to evaluate three real use-cases in agri-food VC defined within the RUC-APS project, and discuss the possibilities of improving the existing knowledge boundaries in those use cases. The RDs were formulated based on consultations with three experts in academia and agri-food industry, who are also involved in the RUC-UPS project.

In our previous attempt to prepare such a DSS (Mileva Boshkoska, Liu, & Chen, 2018), the data preparation step employed a low cardinality keyword set. Consequently, this limited the granularity of the data hence limiting the sensitivity of the complete system. Therefore to obtain better ontology and DSS, in this work, the keyword set was carefully constructed in order to improve the key concepts that comprise the terminology of “knowledge sharing crossing boundaries”. The starting point were the following concepts:

1. Learning, sustainability, development (networks)
2. Cross boundaries education (networks).
3. Innovation, boundary objects (knowledge types).
4. Knowledge sharing, teams (networks).
5. Organization, technology, human/tacit knowledge (knowledge types, networks).

The concepts were used to define the keywords for selection of the most relevant articles in WoS as intersection between the key word “knowledge boundaries” and the above concepts. In the process of pre-processing we selected the most relevant articles, we removed duplicates, such that one article goes only into one concept which lead to removal of the concept “*Learning, sustainability, development*”. However, as shown later in Figure 4, the concept occurs as sub concept of “*Embeded knowledge sharing*”. We also removed the conference articles, which finally resulted in 224 articles from WoS between 2010 and 2018, as shown in Table 1.

Table 1 Total number of selected articles from WoS.

Intersection of key concepts	Number of articles in WoS between 2010-2018
("knowledge boundaries") AND (“cross boundary education”)	3

("knowledge boundaries") AND ("innovation") AND ("boundary objects")	9
("knowledge boundaries") AND ("organization")	39
("embedded knowledge sharing")	76
("explicit knowledge sharing")	51
("tacit knowledge sharing")	46

5 Ontology for knowledge sharing crossing boundaries

Ontologies are a visual and efficient way of representation of domain knowledge encoded in large number of information sources. The construction of the ontology comprises of pre-processing of the downloaded articles so that they are in the format that is suitable for usage of the *OntoGen* software tool. It is a tool that offers a semi-automatic way of construction of an ontology based on automatic topic extraction from the downloaded papers (Fortuna, Grobelnik, & Mladenić, 2005), (Fortuna, Grobelnik, & Mladenić, 2005a). Usually data are given as a bag-of-words which is a text document in which each row represents one instance of data containing, for example, the title, abstract and keywords of one paper. Based on the developed bag-of-words, *OntoGen* software tool automatically suggests concepts, names of concepts, keywords etc. Concepts are the central part in generating ontologies. To generate the concepts, we have used the option of unsupervised learning offered by the *OntoGen* software, which is based on the k-means clustering and latent semantic indexing techniques. User is asked to enter the number of clusters (concepts) and as a result the papers in the bag-of-words are divided according to similarity in the wanted number of concepts. This is an iterative procedure in which each of the concepts may be further divided until the user decides on the granularity of the obtained ontology.

The concept of ontology allows us to overcome the problem of organisation of large number of documents and to provide a visual representation of the concepts. The visualisation of clusters (concepts) in the downloaded documents is presented as a visual map in Figure 3. The visual map shows three major clusters of documents, represented with the light blue colour. However, these clusters of documents are interconnected with documents that deal with more than one selected topic, as represented with darker blue colour in Figure 3. Hence, there are intersections of the different concepts, presented as intersection of ellipses in Figure 3.

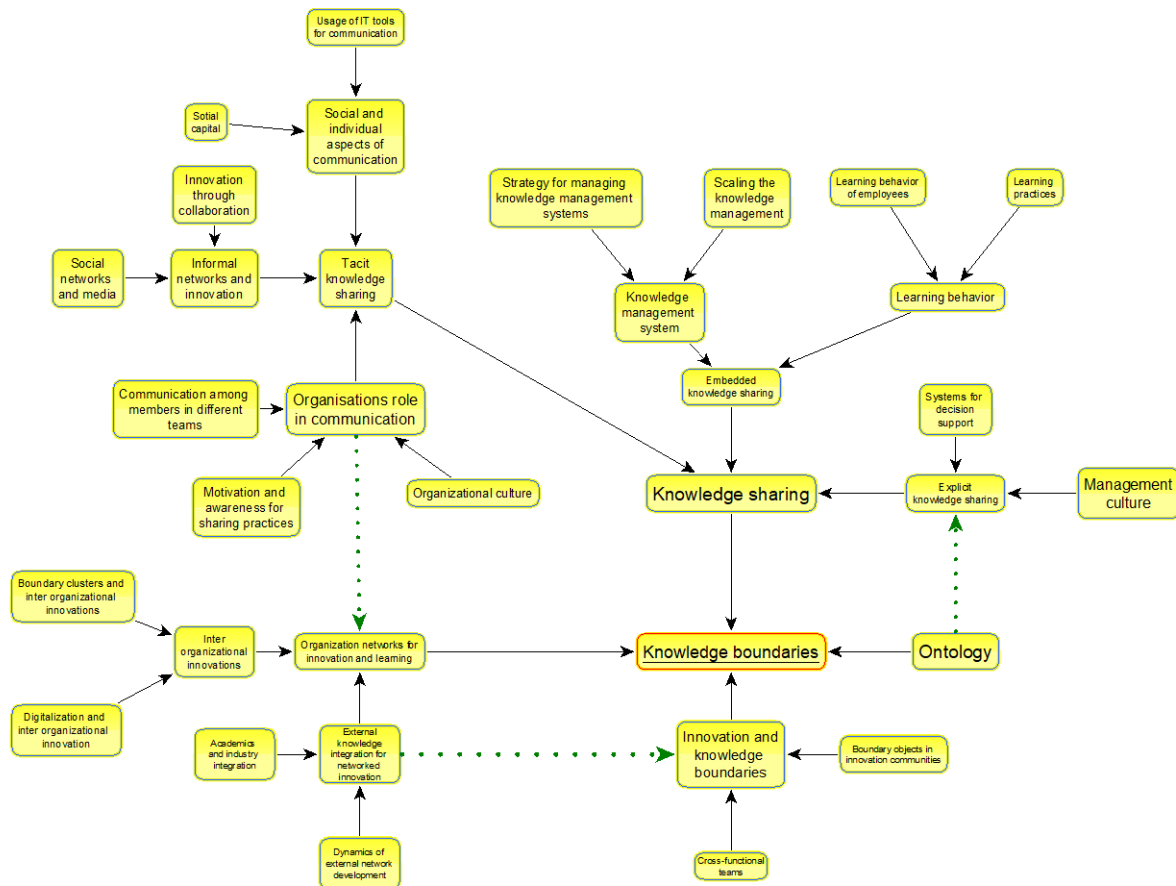


Figure 4 Ontology of concepts that are most commonly used with knowledge boundaries.

Using *OntoGen*, we extracted the following most frequently researched concepts as sub topics of the knowledge boundaries:

1. Ontology
2. Innovation and knowledge boundaries
3. Knowledge sharing
4. Organization networks for innovation and learning

Each of the concepts was further divided into sub concepts, some of which occurring repeatedly. The process ended with the development of the ontology, as shown in Figure 4. The intersection documents that occur in more than one sub-concept are represented with dotted lines in Figure 4. For example, the sub concept “*Organisation role in communication*” is an important one for the evaluation of the “*Tacit knowledge sharing*” in organisations, however it is also important for the evaluation of the formation of “*Organisation networks for innovation and learning*”.

The concept *Ontology* ensures that the existent knowledge is formally defined thus allowing its systematic storage in information systems, its articulation and possibility of its dissemination

(Nonaka, 1994).

5.1 Innovation and knowledge boundaries

The concept *Innovation and knowledge boundaries* comprises three sub categories:

1. Cross-functional teams
2. Boundary objects in innovation communities
3. External knowledge integration for networked innovation – a concept that also occurs in defining the *Organization networks for innovation and learning* concept

Cross-functional teams deals with existence of teams in organizations that are responsible for transferring knowledge from one team to another forming an interdisciplinary environment. These teams have a difficult role of identification, elaboration, confrontation the differences and dependencies across knowledge boundaries in particular when teams are faced with contemporary knowledge (Kotlarsky, van den Hooff, & Houtman, 2015), (Majchrzak, More, & Faraj, 2012).

Boundary objects examines the pragmatic view between knowledge and boundaries and studies the representation of knowledge that helps cross the knowledge boundaries (Smith, Boundary emergence in inter-organizational innovation, 2016), (Marheineke, Habicht, & Moslein, 2016), (Barley, 2015), (Carlile, 2002). In addition it explores how to overcome three progressively complex knowledge boundaries in organizations/networks: syntactic, semantic, and pragmatic (Abraham, Aier, & Winter, 2015), (Rau, Neyer, & Moslein, 2012).

5.2 Knowledge sharing

The concept of *knowledge sharing* is divided into three categories:

1. Explicit knowledge sharing
2. Tacit knowledge sharing
3. Embedded knowledge sharing

This concept groups various documents which deal with knowledge boundaries at newly emerging interfaces for knowledge sharing, knowledge sharing through learning, in particular explorative and exploitative knowledge sharing (Im & Rai, 2008), and behaviour of groups that deal with the contradiction among distributed knowledge in boundary-spanning collaborative processes (Gasson, 2005).

The first category, the *Explicit knowledge sharing*, comprises three interconnected concepts:

1. Ontology – a dependent sub concept from the developed ontology system for *knowledge boundaries*
2. Systems for decision making
3. Management culture

Systems for decision making improve the total profit and due date performance in organisations (Buenemann M. , et al., 2011). *Management culture* defines the role of the management in knowledge sharing. For example, management that allows usage of ICT tools for bottom-up knowledge flow and motivate team work as well as encourage the intrinsic behaviour of their employees lead to better knowledge sharing in organizations.

The second category, the *Tacit knowledge sharing*, comprises three interconnected concepts:

1. Informal networks and innovation
2. Social and individual aspects of communication
3. Organisations role in communication

These three concepts allow successful propagation of tacit knowledge throughout a network. Studies in this field focus on two types of propagation of tacit knowledge: through creation of industry - university links which would serve as a conceptual bridge between internal labour markets and network organizations; and identification of knowledge boundaries that happen in projects and established networks (Swart & Harvey, 2011).

The first concept, *Informal networks and innovation*, is influenced by the existence of different types of collaborations that happen on informal level, however, may lead to unplanned innovations. Another important aspect is the establishment of social networks through existing social media which allow sharing, learning and discussing tacit knowledge.

The second concept, *Social and individual aspects of communication*, comprises the idea of the social capital of the employees and the ability of the employees to use state-of-the-art tools for formal or informal communication.

The last concept that defines *Tacit knowledge*, the *Organisations role in communication*, is important because it defines three aspects of organisational management: organisational culture, the motivation that organisations provide for sharing practices and promotion of such activities with the aim of increasing the awareness of employees for sharing tacit knowledge, as well as allowing a free flow of communication among members belonging to different teams. Teams seem to have an important role in knowledge sharing. The examined papers discuss how to cross the boundaries between different team members, or in particular team leaders. The main boundaries are associated with different knowledge backgrounds of the team members' coming from various disciplines (Fitzgerald & Rowley, 2015), (Lee, Min, & Lee, 2017), (Wannenmacher & Antoine, 2016), when teams are faced with novelty, and co-location of research and development teams in multi-space environment (Majchrzak, More, & Faraj, 2012), (Coradi, Heinzen, & Boutellier, 2015).

The third category, the *Embedded knowledge sharing*, comprises two interconnected concepts:

1. Knowledge management systems
2. Learning behaviour

Sharing embedded knowledge in policies and products needs to be allowed through tools such as *knowledge management systems*. Knowledge management systems are determined by the existence of strategy for managing knowledge management systems and their implementation in companies. The second important factor in knowledge management systems is their scalability i.e. to be able to transfer knowledge from a local organisation branch to its other national or international branches.

Learning behaviour is determined by two factors. The first one is the learning behaviour of employees in organisations which is due to the developed trust, motivation, leadership style, workplace spirituality and social networks embedded in the organization (Rahman, Osman-Gani, Momen, & Islam, 2015). The second one represents the learning practices in the organisation i.e. whether the organisation supports only individual learning or also implements platforms for collaborative learning (Anshari, Alas, & Guan, 2015).

5.3 Organisational networks for innovation and learning

Organisational networks for innovation and learning and the imposed cross-boundaries can be analysed through a variety of aspects such as:

1. Inter organizational networks for innovations
2. External knowledge integration for networked innovation

Inter organizational networks for innovations are defined through two attributes: the role of digitalization in companies in creating and supporting inter organizational innovations, and the boundaries which occur due to forming clusters in organizations responsible for inter organizational innovations. The first attribute contributes towards better knowledge sharing and implies better knowledge flow within the organization; the second one implies forming groups where the knowledge is “hidden” within the organisation. *External knowledge integration for networked innovation* (Burström, Harri, & Wilson, 2018), (Mäenpää, Suominen, & Breite, 2016), (Smith, Boundary emergence in inter-organizational innovation, 2016), (Rehm & Goel, 2015), (Valkering, Beumer, de Kraker, & Ruelle, 2013) deals with external organisational boundaries and is defined through two attributes: existence of networks between the organization and academics, and dynamics of external network development. The first attribute, *academics and industry integration*, describes the company’s needs and possibilities to extend their expertise and knowledge boundaries into the offered markets of the universities with which they collaborate, thus leading to the formation of integrated resources with work

experiences that balance the two sectors (Lam, 2007). It provides insights of how organizations bridge the boundaries between the required technological knowledge found externally, and how they align the obtained external knowledge and organizations strategies associated with improving current, and developing future capabilities. It generalizes the academy – industry crossing of boundaries in a way that the academically gained knowledge can be used both for work and academic requirements (Garraway, 2010), (Young & Muller, 2010). Four learning mechanisms are defined for crossing the academy – industry boundaries: identification, coordination, reflection, and transformation (Akkerman & Bakker, 2011), (Hong & Snell, 2015), (Barley, 2015).

The attribute *dynamics of external network development* describes the company's dynamics in development of external networks with other parties of interest with common goal of sharing practices that may lead to innovations (Burström, Harri, & Wilson, 2018). It focuses on the knowledge exchanges across knowledge boundaries in activities of different organisations, which aim to provide an innovation (Rehm & Goel, 2015), (Smith, Boundary emergence in inter-organizational innovation The influence of strategizing, identification and sensemaking, 2016), functioning of innovation clusters and usage of knowledge brokering activities to cross knowledge boundaries (Castro, 2015); and open innovations (Wilhelm & Dolfma, 2018), which deals with obtaining knowledge from distant knowledge sources.

6 A DSS for knowledge sharing crossing boundaries

This step includes defining the basic concepts of the DSS architecture: a database, a model, and a user interface. The basic model architecture in this research is directly obtained from the developed concepts and relations in the ontology. Next, the model requires definition of rules that would govern the concepts and provide directions of “how” to improve the evaluated alternatives at hand. In this research, alternatives represent three use-cases of agri-food value chain, which we would like to evaluate and find out how to improve their existing knowledge. The problem at hand deals with qualitatively described concepts, thus usage of qualitative decision support techniques is a natural way for the development of the DSS. We have used DEX method (Bohanec, Rajkovič, Bratko, Zupan, & Žnidaršič, 2013) in this research to develop the DSS because it has been previously used successfully in similar fields. In addition, DEX method is implemented in DEXi software tool, which is freely available and easy to use (Bohanec M. , 2015). DEX method is a rule-based qualitative multi-attribute decision modelling methodology. To use DEX, the decision maker uses his/her expert knowledge to define “if-

then” rules for the relation among the attributes in the DSS (for example concepts and its sub concepts). The rules lead to utility functions given in tabular format that represent experts’ opinions, preferences and/or knowledge. In DEX, several attributes are aggregated into one, and the aggregated attribute is propagated to the next higher hierarchical level of the model. The DEX model consists of: attributes, scales of attributes (usually qualitative set of words ordered in a preferential way, such as: 'developed', 'partially developed', 'underdeveloped', etc.), hierarchy of attributes (that represent a decision tree), and decision rules (interpreted as “if-then” rules).

Finally, the evaluation of options is performed. In this phase the user enters all options in the developed model, which evaluates them. In DEX there is a possibility to perform “plus-minus” analysis which allows the user to see how the final evaluation of an option would change if some of the attributes improves their values.

The ontology presented in Figure 4 was used to develop a DSS for evaluation of the knowledge boundaries in agri-food value chains. The structure of the proposed DSS, its attributes, scales of attributes, and hierarchy of attributes for evaluation of the level of knowledge boundaries are given in Figure 5. It is a hierarchical model, where the attribute “*Knowledge boundaries*” is evaluated based on the values of its descendant attributes (sub-concepts): “*Ontology*”, “*Innovation and knowledge boundaries*”, “*Knowledge sharing*”, and “*Organization networks for innovation and learning*”. These attributes, with exception of the attribute “*Ontology*” are aggregated attributes, also called dependent attributes, meaning that their values are obtained indirectly, by using aggregation function over the values of the input attributes. For each aggregated attribute, a utility table is defined by the decision maker in which he/she defines the rules of aggregation from lower level attributes to higher level attributes.

Attribute	Scale
Knowledge boundaries	strong ; medium; weak; <i>none</i>
Innovation and knowledge boundaries	weak ; medium; <i>strong</i>
boundaries objects in innovation communities	undefined ; <i>defined</i>
cross-functional teams	non-existent ; <i>existent</i>
External knowledge integration for networked innovation	underdeveloped ; <i>developed</i>
academics and industry integration	non-existent ; <i>existent</i>
dynamics of external network development	none ; slow; <i>fast</i>
Knowledge sharing	weak ; medium; <i>strong</i>
Explicit knowledge sharing	weak ; medium; <i>strong</i>
systems for decision support	weak ; medium; <i>strong</i>
ontology	non-existent ; <i>existent</i>
Management culture	discouraged ; <i>motivated</i>
employees behaviour	discouraged ; <i>motivated</i>
ICT tools	not available ; <i>available</i>
Tacit knowledge sharing	weak ; medium; <i>strong</i>
Informal networks and innovation	weak ; medium; <i>strong</i>
social networks and media	some ; existent; <i>highly existent</i>
innovation through collaboration	weak ; medium; <i>strong</i>
Social and individual aspects of communication	unsupported ; supported; <i>strongly supported</i>
social capital	some ; existent; <i>highly existent</i>

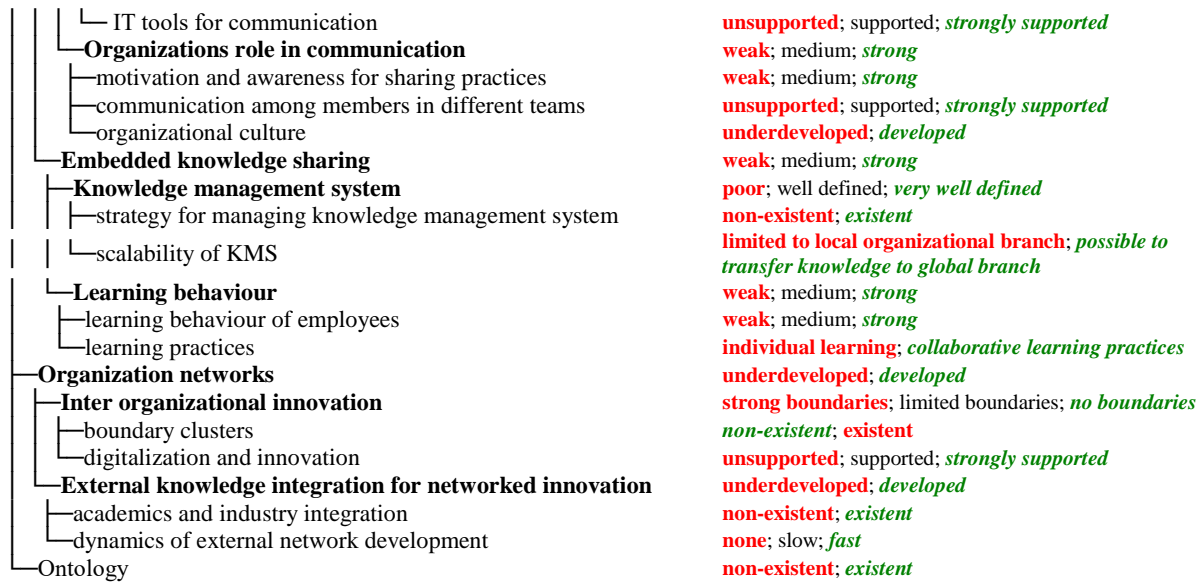


Figure 5 Attributes, scales of attributes, and hierarchy of attributes for evaluation of the level of knowledge boundaries.

An example of a utility table is provided in Table 2 for the attribute “*Inter organisational innovation*”. The qualitative values of the attribute are obtained by aggregating the values of the attributes “*boundary clusters*” and “*digitalization and innovation*”. The aggregation values are given in the Table 2, a utility table in which each row can be represented as an easily understandable “*if-then*” rule. For the given example we may derive the following four rules:

Rule 1:

“**IF** *boundary clusters* **ARE** *existent* **AND** *digitalization boundary clusters* **ARE** *existent* **AND** *digitalization and innovation* **ARE** *unsupported* **THEN** *Inter organisational innovation* **IS** *strongly bounded*”.

Rule 2:

“**IF** *boundary clusters* **ARE** *non existent* **AND** *digitalization and innovation* **ARE** *unsupported* **THEN** *Inter organisational innovation* **HAS** *limited bounded*”.

Rule 3:

“**IF** *boundary clusters* **ARE** *existent* **AND** *digitalization and innovation* **HAS VALUE GRATER THAN OR EQUAL TO** *supported* **THEN** *Inter organisational innovation* **HAS** *limited bounded*”.

Rule 4:

“**IF** *boundary clusters* **ARE** *non existent* **AND** *digitalization and innovation* **HAS VALUE GRATER THAN OR EQUAL TO** *supported* **THEN** *Inter organisational innovation* **HAS** *no boundaries*”.

Table 2 Utility table for the attribute “Inter organisational innovation”.

	boundary clusters	digitalization and innovation	Inter organizational innovation
	67%	33%	
1	existent	unsupported	strong boundaries
2	<i>non existent</i>	unsupported	limited boundaries
3	existent	>=supported	limited boundaries
4	<i>non existent</i>	>=supported	<i>no boundaries</i>

Utility tables for all aggregated attributes in the developed decision support system are given in Appendix A.

7 Evaluation of the DSS

To evaluate the proposed decision support system we have chosen three real agri-food value chains that were part of the RUC-APS project:

- Chinese leaf value chain in China;
- Tomato value chain in Argentina;
- Brassica value chain in the United Kingdom.

These three cases are selected because the Chinese leaf, Argentine (La Plata) tomato, and UK brassica value chains deal with very different products hence require varied knowledge to flow through the chains. Furthermore, the three countries are located in three different continents with varied knowledge sharing cultures. By undertaking comparative analysis across three varied case studies, it allows us to evaluate the DSS and obtain more insights into knowledge-based decision support, in particular, to obtain insights in the transparency and interoperability of data and knowledge crossing boundaries in agri-food value chains. In Figure 6 we present DEXi interface showing the database with the three options and values of their input attributes.

The screenshot shows the DEXi software interface. At the top is a menu bar with 'File', 'Edit', 'Window', and 'Help'. Below it is a toolbar with icons for file operations and model manipulation. A tab labeled 'Model' is active, and a search bar contains 'Chinese leaf small one'. The main area displays a table with four columns: 'Option', 'Chinese leaf small one', 'Argentina tomato big one', and 'UK brassica big one'. The table lists 25 options with their corresponding values for the three scenarios. The status bar at the bottom indicates 'Attributes: 40 (24 basic, 0 linked, 16 aggregate) | Scales: 40 | Functions: 16 | Options: 3'.

Option	Chinese leaf small one	Argentina tomato big one	UK brassica big one
boundaries objects in innovation communities	defined	defined	defined
cross-functional teams	limited	existent	existent
academics and industry integration	existent	existent	existent
dynamics of external network development	fast	slow	fast
systems for decision support	medium	weak	strong
employees behaviour	discouraged	discouraged	motivated
usage of ICT tools for knowledge sharing	not available	not available	available
ontology	existent	existent	existent
social networks and media	existent	existent	highly existent
innovation through collaboration	medium	weak	strong
social capital	existent	some	highly existent
IT tools for communication	supported	supported	supported
motivation and awareness for sharing practices	weak	weak	medium
communication among members in different teams	supported	supported	strongly supported
organizational culture	underdeveloped	underdeveloped	developed
strategy for managing knowledge management system	existent	non existent	existent
scalability of KMS	possible to transfer knowledge to global branch	limited to local organizational branch	possible to transfer knowledge to global branch
learning behavior of employees	strong	strong	strong
learning practices	collaborative learning practices	collaborative learning practices	collaborative learning practices
boundary clusters	existent	existent	existent
digitalization and innovation	supported	unsupported	strongly supported
academics and industry integration	existent	existent	existent
dynamics of external network development	fast	slow	fast
ontology	existent	existent	existent

Figure 6 DEXi interface showing the database with three options and values of their input attributes.

7.1 Description of the Chinese leaf value chain

The *Chinese leaf value chain* is schematically represented in Figure 7. Agri-food research institutions/universities mainly transfer their pest control knowledge with farmers/producers. Seed and agri-chemical sellers provide the information on which seed and which agri-chemical product are the best one for farmers/producers. After harvesting Chinese leaf, farmers/producers would sell their part of products to the local consumers directly. Some large farmers/producers (more than 40 employees) have the capability to sell the Chinese leaf products to the wholesalers in other places directly in order to earn more money. But most of the products would be sold by farmers/producers to the distributors or wholesalers in the producing area. Then, the Chinese leaf products would be sold by local distributors/wholesalers to the wholesalers in other places. Next, in other places, the products would be sold by wholesalers to small retailers in the markets, supermarkets, hotels, restaurants and government organizations (such as military). Finally, consumers can buy products through different ways.

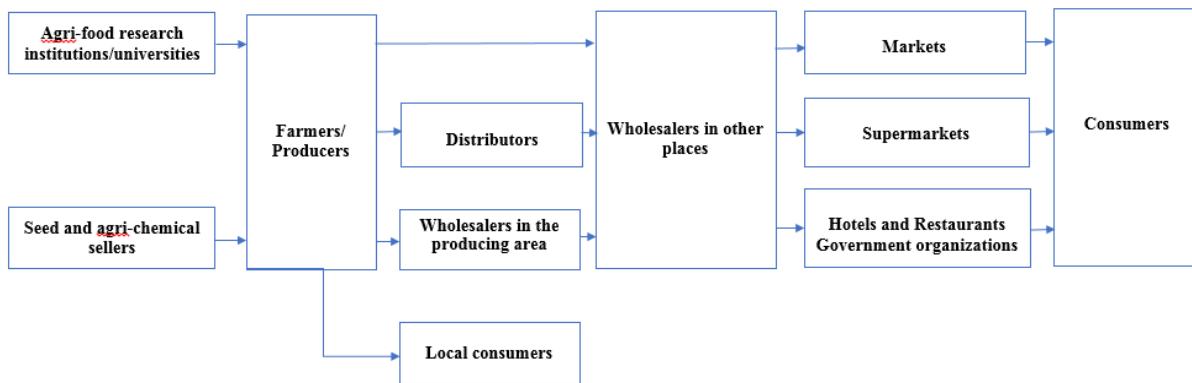


Figure 7 Chinese leaf value chain in China.

7.2 Description of fresh tomato value chain in La Plata/Buenos Aires peri-urban region, Argentina

The case of *fresh tomato value chain in La Plata, Argentina* is presented in Figure 8. The Horticultural peri-urban of La Plata has shown an interrupted economic, productive, technological, and commercial growth and in the last decades and this quantitative growth has been accompanied by a qualitative differentiation, expressed in a better product quality, extension of the supply period and an increase in the number of producers. One hundred percent of the tomato production in this region is destined for fresh consumption, mainly to the densest population centre in Argentina, the Autonomous City of Buenos Aires and its surroundings which comprises 15 million people.

In La Plata (Argentina), most tomatoes are cultivated in greenhouses (1900 hectares) Medium and large (or more capitalized) farmers/producers are more likely to produce tomatoes, whereas small farmers are more likely to produce leaf vegetables. Large producers sell mostly in supermarkets and to the Central Market of Argentina (in Buenos Aires).

All the products' quality needs to be checked through two different ways: (1) there is an inspector in the Central Market to check the quality; (2) take some samples to the lab to check the quality of the product. In the central market, more than 50% sellers are wholesalers, 10-15% sellers are agent and rest of them are producers and cooperatives. The buyers in the Central Market can be divided into 7 different groups, which are large scale retailers, small retailers, wholesalers, restaurants, government organizations, supermarkets and independent buyers. Finally, these retailers will sell tomatoes to consumers. The large producers sell directly to supermarkets.

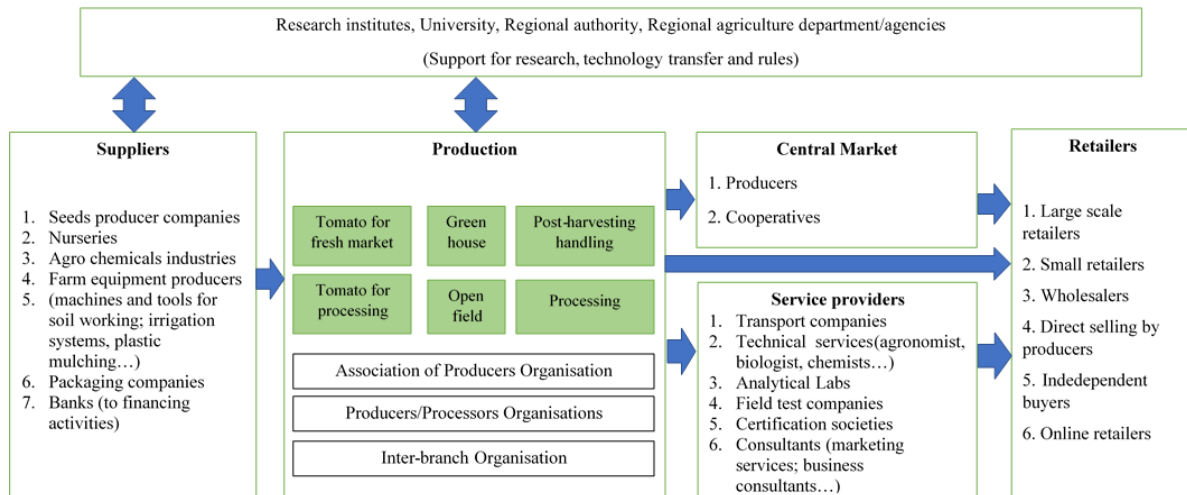


Figure 8 Argentine (La Plata) tomato value chain.

7.3 Description of the United Kingdom brassica value chain

Figure 9 shows the *United Kingdom (UK) brassica value chain*. Most of the information is the same as in the case of Chinese leaf value chain and Argentine tomato value chain. The only difference is the retailer, meaning that most of the brassica are sold through the supermarkets such as Tesco.

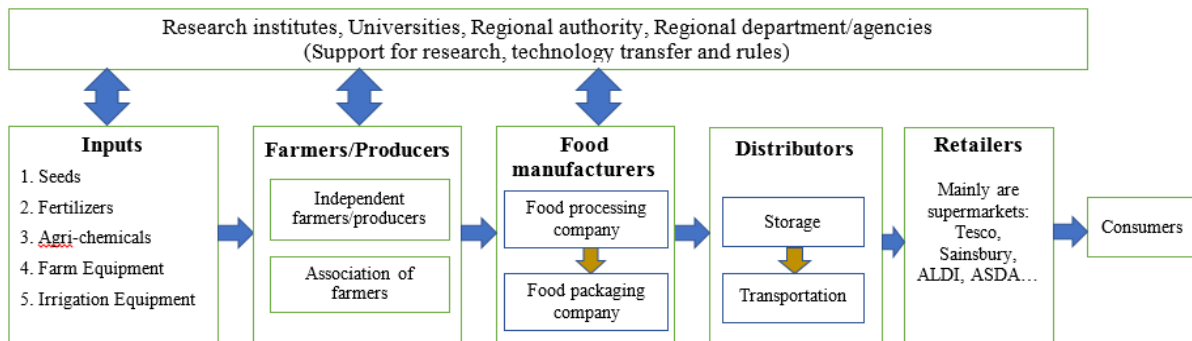


Figure 9 United Kingdom brassica value chain.

7.4 Evaluation of the three agri-food value chains

The evaluation results of the three examples of agri-food value chains is given in Table 3. All attributes are colour coded so that the green colour represents the most preferred attribute value and the red colour represents the least preferred attribute value. The final evaluation for knowledge boundaries of leaf, tomato and brassica value chains are *weak*, *medium:weak* and *none*, respectively.

Table 3 Evaluation of three agri-food value chains.

Attribute	Chinese leaf small one	Argentine tomato big one	UK brassica big one
Knowledge boundaries	weak	medium; weak	<i>none</i>
└─ Innovation and knowledge boundaries	medium	<i>strong</i>	<i>strong</i>
└─└─boundaries objects in innovation communities	<i>defined</i>	<i>defined</i>	<i>defined</i>
└─└─cross-functional teams	limited	<i>existent</i>	<i>existent</i>
└─ External knowledge integration for networked innovation	<i>developed</i>	<i>developed</i>	<i>developed</i>
└─└─academics and industry integration	<i>existent</i>	<i>existent</i>	<i>existent</i>
└─└─dynamics of external network development	<i>fast</i>	slow	<i>fast</i>
└─ Knowledge sharing	medium	<i>weak</i>	<i>strong</i>
└─└─ Explicit knowledge sharing	medium	<i>weak</i>	<i>strong</i>
└─└─└─systems for decision support	medium	<i>weak</i>	<i>strong</i>
└─└─└─ Management culture	<i>discouraged</i>	<i>discouraged</i>	<i>motivated</i>
└─└─└─└─employees behaviour	<i>discouraged</i>	<i>discouraged</i>	<i>motivated</i>
└─└─└─usage of ICT tools for knowledge sharing	<i>not available</i>	<i>not available</i>	<i>available</i>
└─└─└─ontology	<i>existent</i>	<i>existent</i>	<i>existent</i>
└─└─ Tacit knowledge sharing	medium	<i>weak</i>	<i>strong</i>
└─└─└─ Informal networks and innovation	medium	<i>weak</i>	<i>strong</i>
└─└─└─└─social networks and media	existent	existent	<i>highly existent</i>
└─└─└─innovation through collaboration	medium	<i>weak</i>	<i>strong</i>
└─└─ Social and individual aspects of communication	supported	supported	<i>strongly supported</i>
└─└─└─social capital	existent	<i>some</i>	<i>highly existent</i>
└─└─└─IT tools for communication	supported	supported	supported
└─└─ Organizations role in communication	<i>weak</i>	<i>weak</i>	<i>strong</i>
└─└─└─motivation and awareness for sharing	<i>weak</i>	<i>weak</i>	medium
└─practices			
└─└─communication among members in different teams	supported	supported	<i>strongly supported</i>
└─└─└─organizational culture	<i>underdeveloped</i>	<i>underdeveloped</i>	<i>developed</i>
└─└─ Embedded knowledge sharing	<i>strong</i>	<i>weak</i>	<i>strong</i>
└─└─└─ Knowledge management system	<i>very well defined</i>	<i>poor</i>	<i>very well defined</i>
└─└─└─strategy for managing knowledge management system	<i>existent</i>	<i>non existent</i>	<i>existent</i>
└─└─└─scalability of KMS	<i>possible to transfer knowledge to global branch</i>	<i>limited to local organizational branch</i>	<i>possible to transfer knowledge to global branch</i>
└─└─ Learning behavior	<i>strong</i>	<i>strong</i>	<i>strong</i>
└─└─└─learning behavior of employees	<i>strong</i>	<i>strong</i>	<i>strong</i>
└─└─└─learning practices	<i>collaborative learning practices</i>	<i>collaborative learning practices</i>	<i>collaborative learning practices</i>
└─ Organization networks	<i>developed</i>	<i>underdeveloped</i>	<i>developed</i>
└─└─ Inter organizational innovation	limited	<i>strong boundaries</i>	limited
└─└─└─boundary clusters	boundaries	<i>existent</i>	boundaries
└─└─└─digitalization and innovation	<i>existent</i>	<i>existent</i>	<i>existent</i>
└─└─ External knowledge integration for networked innovation	<i>developed</i>	<i>developed</i>	<i>developed</i>
└─└─└─academics and industry integration	<i>existent</i>	<i>existent</i>	<i>existent</i>
└─└─└─dynamics of external network development	<i>fast</i>	slow	<i>fast</i>
└─ontology	<i>existent</i>	<i>existent</i>	<i>existent</i>

The evaluation of the attributes for each of the value chains was performed between a decision analyst and a knowledge management expert involved in the RUC-UPS project. The rationale for evaluation of the attributes is given in continuation.

The evaluation of the attribute *Innovation and knowledge boundaries*, comprises evaluation of three other attributes, from which two differ in their evaluations for the presented agri-food value chains. The first attribute, *cross-functional teams*, is evaluated as *existent*, for Argentine tomato and UK brassica, and as *limited*, for Chinese leaf. In all three agri-food value chains farmers usually attend different trainings to learn about new technologies used in the fields, for example how to use new chemicals. The main difference is that Chinese leaf farm is considered as a small one, while farms for Argentine tomato and UK brassica are considered as large farms. There is a difference between small and large farms, in the approach that they use for forming cross-functional teams. While small farms usually attend trainings outside their farms (in training centres, free academia courses, free sessions organized by non-governmental organisations) which happen rarely, large farms frequently pay to experts and private organizations to come and educate them on the field. Farmers working on small farms are willing to cooperate and gain knowledge, however due to finances they have limited cross functional teams. Hence, the evaluation of the *cross-functional teams* attribute for the Chinese leaf value chain as *limited*. The second difference is in the evaluation of the attribute *dynamics of external networks development*. In particular, for the case of Argentine tomato VC it is considered that the dynamics of networks development is *slow*, due to the fact that farmers are not encouraged to share their practices with other parties.

The evaluation showed that *Explicit knowledge sharing* is *weak* for Argentine tomato VC, *medium* for Chinese leaf VC and *strong* for UK brassica VC. The rationale is based on three attributes. The first one, *systems for decision support*, is *weak* in Argentine tomato VC. Although a system has been procured for assessment of weather risks, and it has been connected to a system to share information between farmers as alarms regarding the conditions of pests, still the system is not yet widely used. On the other hand, in Chinese leaf VC are invited to visit the farmers and help them in making professional decisions. Finally, UK has in place advanced ICT systems that farmers use for communication: there is a weather system in place and a system for determining the pests. The next differences are in the evaluation of the *Explicit knowledge sharing* are in the *employees' behaviour*. In Argentine tomato VC, there is a reward system to keep skilled farmers at work, thus there is no need to encourage them to learn other

new skills. In China, farms for Chinese leafs are very frequent, thus the existent knowledge is sufficient and there is no need to gain further knowledge or to explicitly share it. In UK brassica VC, it is common for farmers to visit other farms and sell their knowledge, for example, farmers frequently sell their knowledge about how they operate their farms.

The third difference among VCs is in the usage of ICT tools for knowledge sharing. Although today it is a common understanding that everyone has access to ICT tools, the management culture in Chinese leaf VC and Argentine tomato VC is such that it is reluctant to use ICT for knowledge sharing as actors in the VCs frequently regard their knowledge about the processes in the VCs as secrets. On the other hand, in UK brassica VC, it is allowed to use state-of-the-art tools for formal and informal communication and all actors in the VC are encouraged to use them in order to gain or share knowledge among themselves.

Regarding *tacit knowledge sharing*, the three VCs differ in evaluation of six attributes. The first one, *social networks and media*, is evaluated as existent in VCs for Argentine tomato and Chinese leaf, however they happen in an informal manner. The attribute *innovation through collaboration*, is considered as *weak* for Argentine tomato VC, where farmers collaborate with NGOs and universities, and project their collaborations there such as testing a certain pest, or searching for ways to reduce the pest risk. Due to very limited finances such projections are rare.

In the Chinese leaf VC the situation is the same as in Argentine tomato VC, but in addition the projections happen on a regular basis. In UK brassica VC all companies in the value chain use projections which are not limited only to the cooperation between academia and farmers. The next attribute, *social capital*, in Chinese leaf VC is evaluated as *existent* since there are companies that invest in agriculture leading to availability of new technologies thus making possibilities for development of the social capital. In Argentine tomato VC there is a limited number of such companies compared to China tomato VC. The attribute *motivation and awareness for sharing practices* in Argentine tomato VC and Chinese leaf VCs is considered as *weak* as the sharing practices happen within the farms, however outside the organizations it is not encouraged and sometimes it does not exist at all. On the other hand in UK brassica VC it is common practice to visit different farms to obtain other knowledge about operation practices. The same rationale applies for communication among members of different teams, which is supported within organisations in Argentina and China, however not encouraged between teams from different organisations. The last attribute is *organizational culture*, which for Chinese leaf VC and Argentine tomato VC is considered as *underdeveloped*, as simply the culture of the two VCs is such that sharing tacit knowledge is not supported.

Regarding *embedded knowledge sharing* the three VCs differ in the evaluation of two attributes. The attribute *strategy for managing knowledge management system* is considered as *non existent*, and the scalability of KMS are limited only to local organizational units for the Argentine tomato VC.

The *Organisation networks* differ in the evaluation of two attributes. The first one, *digitalization and innovation*, is evaluated as *unsupported* in Argentine tomato VC due to the approach for spending the available finances, which are usually dedicated to buying a new equipment for the fields, instead of investing in knowledge management equipment and tools. Due to limited finances the evaluation for Chinese leaf VC is evaluated as *supported*. The next attribute, *dynamics of external network development*, is also a part of the evaluation of the *Innovation and knowledge boundaries*, and it is already explained earlier.

DEXi software incorporates plus-minus analysis, which allows to see the effects of changing each basic attribute by one value (if possible), independently of other attributes, on the evaluation of a selected aggregated attribute.

The evaluation showed that the best results for knowledge sharing crossing boundaries are for the UK brassica VC. Despite such a result, the analysis identified two attributes that might be improved: *motivation and awareness for sharing practices* and *IT tools for communications*. This is understandable given the fact that IT tools are perpetually improved and companies lag in adopting the newest practices.

The plus-minus analysis shows that the *knowledge boundaries* of the Chinese leaf VC may be improved for one value up (from weak to none), if at least two of the attributes *cross-functional teams*, *boundaries objects* and *motivation and awareness for sharing practices* improve. The change would lead the evaluation of the knowledge boundaries from the interval *weak* to *none*. The knowledge boundaries of the Argentine tomato VC may improve by improving the value of the attribute *digitalization and innovation* from *unsupported* to *weak*. The change would lead the evaluation of the knowledge boundaries from the interval *medium:weak*, to only *weak*.

Finally, we conclude that the proposed approach enables the evaluation of knowledge sharing agri-food crossing boundaries in agree-food values chains with different sizes.

8 Conclusion

The paper presents a new DSS for evaluation of knowledge boundaries in agri-food value chains based on a new ontology and new decision rules for the evaluation of the concept of knowledge

sharing crossing boundaries. By increasing the granularity of the ontology we were able to obtain more detailed dependent and independent relations among concepts that define the state-of-the-art concepts of knowledge sharing crossing boundaries in agri-food VCs. Such an increased granularity led towards a comprehensive DSS with 22 input attributes.

The effectiveness of the developed DSS was evaluated on three real agri-food value chains in three continents, which are used as use cases from the RUC-APS project. In particular, we evaluated knowledge boundaries for Chinese leaf value chain, Argentine tomato value chain and UK brassica value chain. In addition, we performed a plus-minus analysis that explains which of the sub concepts that define knowledge boundaries needs to be improved in order to improve the crossing of knowledge boundaries in the three agri-food value chains.

Regardless of the evaluated case, the methodology was able to identify the points that need improvement in order to advance the knowledge sharing crossing boundaries. For the case of UK brassica VC, despite being evaluated as well developed, the proposed DSS was able to identify two weak attributes that should be somewhat improved. For the cases of Argentine tomato and Chinese leaf VCs, multiple weak points were identified and the plus-minus analysis showed that both VCs can be significantly improved by changing only a few attributes such as: *cross-functional teams*, *boundaries objects* for Chinese leaf VC, and *motivation and awareness for sharing practices*, and *digitalization and innovation* for Argentine tomato VC.

Although the presented results cover a specific problem of agri-food VCs, the proposed methodology is broadly applicable. The methodology requires only two user inputs during the development stage: the domain knowledge keyword set and the *if-then* evaluation rules. Consequently, the proposed approach can be easily upgraded or even extended to different areas and problems that include identification of knowledge management concepts. In addition, the future work may include improvement of the ontology by adding other sources of research articles, for example adding conference papers, or adding research article from several other data bases.

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10 References

- Abedi, V., Yeasin, M., & Zand, R. (2014). Empirical study using network of semantically related associations in bridging the knowledge gap. *Journal of Translational Medicine*, 12(1), 324.
- Abraham, R., Aier, S., & Winter, R. (2015). Crossing the Line: Overcoming Knowledge Boundaries in Enterprise Transformation. *BUSINESS & INFORMATION SYSTEMS ENGINEERING*, 11.
- Akkerman, S. F., & Bakker, A. (2011). Boundary Crossing and Boundary Objects. *Review of Educational Research*, 132-169.
- Alin, P., Iorio, J., & Taylor, J. (2013). Digital Boundary Objects as Negotiation Facilitators: Spanning Boundaries in Virtual Engineering Project Networks. *PROJECT MANAGEMENT JOURNAL*, 16.
- Anshari, M., Alas, Y., & Guan, L. (2015). Pervasive knowledge, social networks, and cloud computing: E-learning 2.0. *Eurasia Journal of Mathematics, Science and Technology Education*.
- Baert, A., Clays, E., Bolliger, L., De Smedt, D., Lustrek, M., Vodopija, A., . . . Pardaens, S. (2018, 12 27). A Personal Decision Support System for Heart Failure Management (HeartMan): study protocol of the HeartMan randomized controlled trial. *BMC Cardiovascular Disorders*, 18(1), 186.
- Barley, W. (2015). Anticipatory Work: How the Need to Represent Knowledge Across Boundaries Shapes Work Practices Within Them. *ORGANIZATION SCIENCE*, 17.
- Bohanec, M. (2015). *DEXi: Program for multi-attribute decision making, User's manual, version 5.00*. Ljubljana: Jožef Stefan Institute. IJS Report DP-11897. Ljubljana. Retrieved from <http://kt.ijs.si/MarkoBohanec/pub/DEXiManual500.pdf>
- Bohanec, M., Boshkoska, B., Prins, T., & Kok, E. (2017, 1). SIGMO: A decision support System for Identification of genetically modified food or feed products. *Food Control*, 71, 168-177.
- Bohanec, M., Miljković, D., Valmarska, A., Mileva Boshkoska, B., Gasparoli, E., Gentile, G., . . . Konitsiotis, S. (2018, 5 15). A decision support system for Parkinson disease management: expert models for suggesting medication change. *Journal of Decision Systems*, 27(sup1), 164-172.
- Bohanec, M., Rajkovič, V., Bratko, I., Zupan, B., & Žnidaršič, M. (2013). DEX methodology: Three decades of qualitative multi-attribute modelling. *Informatica*, 49 - 54.
- Buenemann, M., Martius, C., Jones, J. W., Herrmann, S. M., Klein, D., Mulligan, M., . . . Ojima, D. (2011). Integrative geospatial approaches for the comprehensive monitoring and assessment of land management sustainability: Rationale, Potentials, and Characteristics. *Land Degradation & Development*, 226-239.
- Buenemann, M., Martius, C., Jones, J., Herrmann, S., Klein, D., Mulligan, M., . . . Ojima, D. (2011, 3). Integrative geospatial approaches for the comprehensive monitoring and assessment of land

- management sustainability: Rationale, Potentials, and Characteristics. *Land Degradation & Development*, 22(2), 226-239.
- Burström, T., Harri, J., & Wilson, T. (2018, 3). Nascent Entrepreneurs Managing in Networks: Equivocality, Multiplexity and Tie Formation. *Journal of Enterprising Culture*, 26(01), 51-83.
- Carlile, P. (2002). A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development. *Organization Science*, 442-455.
- Carlile, P. (2004). Transferring, Translating, and Transforming: An Integrative Framework for Managing Knowledge Across Boundaries. *Organization Science*, 555-568.
- Castro, L. (2015). Strategizing across boundaries: revisiting knowledge brokering activities in French innovation clusters. *JOURNAL OF KNOWLEDGE MANAGEMENT*, 21.
- Chen, H., Liu, S., & Oderanti, F. (2017). A knowledge network and mobilisation framework for lean supply chain decisions in agri-food industry. *International Journal of Decision Support System Technology*, 37-48.
- Coradi, A., Heinzen, M., & Boutellier, R. (2015). Designing workspaces for cross-functional knowledge-sharing in R&D: the "co-location pilot" of Novartis. *JOURNAL OF KNOWLEDGE MANAGEMENT*, 21.
- Craheix, D., Bergez, J.-E., Angevin, F., Bockstaller, C., Bohanec, M., Colomb, B., . . . Sadok, W. (2015, 10 23). Guidelines to design models assessing agricultural sustainability, based upon feedbacks from the DEXi decision support system. *Agronomy for Sustainable Development*, 35(4), 1431-1447.
- Dougherty, D., & Dunne, D. (2012). Digital Science and Knowledge Boundaries in Complex Innovation. *ORGANIZATION SCIENCE*, 18.
- Fitzgerald, R., & Rowley, C. (2015). How have Japanese multinational companies changed? Competitiveness, management and subsidiaries. *ASIA PACIFIC BUSINESS REVIEW*, 8.
- Fortuna, B., Grobelnik, M., & Mladenić, D. (2005). *D1.7.1 Ontology generation from scratch, SEKT Deliverable*. Ljubljana: EU-IST Project IST-2003-506826 SEKT: Semantically Enabled Knowledge Technologies.
- Fortuna, B., Grobelnik, M., & Mladenić, D. (2005a). *D1.9.1 Simultaneous ontologies*. Ljubljana: EU-IST Project IST-2003-506826 SEKT: Semantically Enabled Knowledge Technologies.
- Fu, J., Li, Y., & Wang, X. (2011, 12). Complete Information Dynamic Game Analysis in Tacit Knowledge Sharing Process within Modern Companies. *Advanced Materials Research*, 421, 553-558.
- Garraway, J. (2010). Knowledge boundaries and boundary-crossing in the design of work-responsive university curricula. *Teaching in Higher Education*, 211-222.
- Gasson, S. (2005). The dynamics of sensemaking, knowledge, and expertise in collaborative, boundary-spanning design. *Journal of computer-mediated communication*.
- Hartwich, F., Pérez, M., Ramos, L., & Soto, J. (2007). Knowledge management for agricultural innovation: lessons from networking efforts in the Bolivian Agricultural Technology System. *Knowledge management for development journal*, 21-37.

- Hong, J., & Snell, R. (2015). Boundary-crossing and the localization of capabilities in a Japanese multinational firm. *ASIA PACIFIC BUSINESS REVIEW*, 19.
- Hustad, E. (2017, 11 11). Knowledge Management in Distributed Work: Implications for Boundary Spanning and its Design. *Journal of Integrated Design and Process Science*, 21(1), 25-41.
- Im, G., & Rai, A. (2008). Knowledge sharing ambidexterity in long-term interorganizational relationships. *Management science*, 1281 - 1296.
- Kotlarsky, J., van den Hooff, B., & Houtman, L. (2015, 4 26). Are We on the Same Page? Knowledge Boundaries and Transactive Memory System Development in Cross-Functional Teams. *Communication Research*, 42(3), 319-344.
- Lam, A. (2007). Knowledge networks and careers: Academic scientists in industry-university links. *Journal of Management Studies*.
- Lee, J., Min, J., & Lee, H. (2017). Setting a knowledge boundary across teams: knowledge protection regulation for inter-team coordination and team performance. *JOURNAL OF KNOWLEDGE MANAGEMENT*, 21.
- Lee, J., Min, J., & Lee, H. (2017, 4 3). Setting a knowledge boundary across teams: knowledge protection regulation for inter-team coordination and team performance. *Journal of Knowledge Management*, 21(2), 254-274.
- Mäenpää, S., Suominen, A., & Breite, R. (2016). Boundary Objects as Part of Knowledge Integration for Networked Innovation. *Technology Innovation Management Review*.
- Majchrzak, A., More, P., & Faraj, S. (2012). Transcending Knowledge Differences in Cross-Functional Teams. *ORGANIZATION SCIENCE*, 20.
- Majchrzak, A., More, P., & Faraj, S. (2012, 8). Transcending Knowledge Differences in Cross-Functional Teams. *Organization Science*, 23(4), 951-970.
- Marheineke, M., Habicht, H., & Moslein, K. (2016). Bridging knowledge boundaries: the use of boundary objects in virtual innovation communities. *R & D MANAGEMENT*, 11.
- Mileva Boshkoska, B., Liu, S., & Chen, H. (2018). Towards a knowledge management framework for crossing knowledge boundaries in agricultural value chain. *Journal of Decision Systems*, 27.
- Muniz, J., Dias Batista, E., & Loureiro, G. (2010, 10 26). Knowledge-based integrated production management model. *Journal of Knowledge Management*, 14(6), 858-871.
- Nguyen, H. (2017, 11). Managing Knowledge Integration across Boundaries Fredrick Tell, Christian Berggren, Stefano Brusoni, and Andrew Van de Ven (eds) Oxford University Press, 2017, 305 pp., £55. ISBN: 9780198785972. *Industrial Relations Journal*, 48(5-6), 518-520.
- Nonaka, I. (1994). A Dynamic Theory of Organizational Knowledge Creation. *Organization Science*.
- Rahman, M., Osman-Gani, A., Momen, M., & Islam, N. (2015, 12 1). Testing knowledge sharing effectiveness: trust, motivation, leadership style, workplace spirituality and social network embedded model. *Management & Marketing*, 10(4), 284-303.
- Rau, C., Neyer, A., & Moslein, K. (2012). Innovation practices and their boundary-crossing mechanisms: a review and proposals for the future. *TECHNOLOGY ANALYSIS & STRATEGIC MANAGEMENT*, 37.

- Ravnikar, T., Bohanec, M., & Muri, G. (2016, 4 30). Monitoring and assessment of anthropogenic activities in mountain lakes: a case of the Fifth Triglav Lake in the Julian Alps. *Environmental Monitoring and Assessment*, 188(4), 253.
- Rehm, S., & Goel, L. (2015). The emergence of boundary clusters in inter-organizational innovation. *INFORMATION AND ORGANIZATION*, 25.
- Rehm, S.-V., & Goel, L. (2015, 1). The emergence of boundary clusters in inter-organizational innovation. *Information and Organization*, 25(1), 27-51.
- Reychav, I., & Weisberg, J. (2010, 4 6). Bridging intention and behavior of knowledge sharing. *Journal of Knowledge Management*, 14(2), 285-300.
- Smith, P. (2016, 1 11). Boundary emergence in inter-organizational innovation. *European Journal of Innovation Management*, 19(1), 47-71.
- Smith, P. (2016). Boundary emergence in inter-organizational innovation The influence of strategizing, identification and sensemaking. *EUROPEAN JOURNAL OF INNOVATION MANAGEMENT*, 25.
- Smolyakov, V. (2016, 4 21). Limitation of LDA (latent dirichlet allocation). Retrieved from <https://stats.stackexchange.com/q/208630>
- Swart, J., & Harvey, P. (2011). Identifying knowledge boundaries: the case of networked projects. *Journal of Knowledge Management*, 703-721.
- Tell, F., Berggren, C., Brusoni, S., & Van de Ven, A. (2017). *Managing Knowledge Integration Across Boundaries*. Oxford: Oxford Scholarship Online.
- Valkering, P., Beumer, C., de Kraker, J., & Ruelle, C. (2013, 6). An analysis of learning interactions in a cross-border network for sustainable urban neighbourhood development. *Journal of Cleaner Production*, 49, 85-94.
- Wannenmacher, D., & Antoine, A. (2016). Management of innovative collaborative projects: Moments of tension and the Peer-Mediation Process-a case-study approach. *KNOWLEDGE MANAGEMENT RESEARCH & PRACTICE*, 11.
- Wilhelm, M., & Dolfsma, W. (2018). Managing knowledge boundaries for open innovation - lessons from the automotive industry. *INTERNATIONAL JOURNAL OF OPERATIONS & PRODUCTION MANAGEMENT*, 19.
- Wilhelm, M., & Dolfsma, W. (2018, 1 2). Managing knowledge boundaries for open innovation – lessons from the automotive industry. *International Journal of Operations & Production Management*, 38(1), 230-248.
- Young, M., & Muller, J. (2010). Three Educational Scenarios for the Future: lessons from the sociology. *EUROPEAN JOURNAL OF EDUCATION*, 17.
- Zarate, P., & Liu, S. (2016). A new trend for knowledge-based decision support systems design. *International Journal of Information and Decision Sciences*, 305-324.

Appendix A: Utility tables for aggregated attributes in the developed decision support system

The star “*” in all subsequent utility tables stands for “any value” of the scale for the corresponding attribute.

Table 4 Utility table for Knowledge boundaries.

	Innovation and knowledge boundaries	Knowledge sharing	Organization networks	ontology	Knowledge boundaries
	20%	20%	30%	30%	
1	weak	weak	underdeveloped	*	strong
2	weak	weak	*	nonexistent	strong
3	weak	*	underdeveloped	nonexistent	strong
4	*	weak	underdeveloped	nonexistent	strong
5	weak	<=medium	<i>developed</i>	<i>existent</i>	medium
6	<=medium	weak	<i>developed</i>	<i>existent</i>	medium
7	weak	medium	*	<i>existent</i>	medium
8	<=medium	>=medium	underdeveloped	<i>existent</i>	medium
9	*	medium	underdeveloped	<i>existent</i>	medium
10	weak	medium	<i>developed</i>	*	medium
11	<=medium	>=medium	<i>developed</i>	nonexistent	medium
12	*	medium	<i>developed</i>	nonexistent	medium
13	medium	weak	*	<i>existent</i>	medium
14	medium	*	underdeveloped	<i>existent</i>	medium
15	>=medium	<=medium	underdeveloped	<i>existent</i>	medium
16	medium	weak	<i>developed</i>	*	medium
17	medium	*	<i>developed</i>	nonexistent	medium
18	>=medium	<=medium	<i>developed</i>	nonexistent	medium
19	medium	>=medium	underdeveloped	*	medium
20	medium	>=medium	*	nonexistent	medium
21	>=medium	medium	underdeveloped	*	medium
22	>=medium	medium	*	nonexistent	medium
23	>=medium	>=medium	underdeveloped	nonexistent	medium
24	<=medium	>=medium	<i>developed</i>	<i>existent</i>	weak
25	*	medium	<i>developed</i>	<i>existent</i>	weak
26	<=medium	<i>strong</i>	*	<i>existent</i>	weak
27	*	<i>strong</i>	underdeveloped	<i>existent</i>	weak
28	<=medium	<i>strong</i>	<i>developed</i>	*	weak
29	*	<i>strong</i>	<i>developed</i>	nonexistent	weak
30	medium	*	<i>developed</i>	<i>existent</i>	weak
31	>=medium	<=medium	<i>developed</i>	<i>existent</i>	weak
32	medium	>=medium	*	<i>existent</i>	weak
33	>=medium	medium	*	<i>existent</i>	weak
34	>=medium	>=medium	underdeveloped	<i>existent</i>	weak
35	medium	>=medium	<i>developed</i>	*	weak
36	>=medium	medium	<i>developed</i>	*	weak
37	>=medium	>=medium	<i>developed</i>	nonexistent	weak
38	medium	<i>strong</i>	*	*	weak
39	>=medium	<i>strong</i>	underdeveloped	*	weak
40	>=medium	<i>strong</i>	*	nonexistent	weak
41	<i>strong</i>	<=medium	*	<i>existent</i>	weak
42	<i>strong</i>	*	underdeveloped	<i>existent</i>	weak
43	<i>strong</i>	<=medium	<i>developed</i>	*	weak
44	<i>strong</i>	*	<i>developed</i>	nonexistent	weak
45	<i>strong</i>	medium	*	*	weak
46	<i>strong</i>	>=medium	underdeveloped	*	weak
47	<i>strong</i>	>=medium	*	nonexistent	weak
48	<i>strong</i>	<i>strong</i>	<i>developed</i>	<i>existent</i>	<i>none</i>

Table 5 Utility table for Innovation and knowledge boundaries.

	boundaries objects in innovation communities	cross-functional teams	External knowledge integration for networked innovation	Innovation and knowledge boundaries
	39%	22%	39%	
1	undefined	<=limited	*	weak
2	undefined	*	underdeveloped	weak
3	*	<=limited	underdeveloped	weak
4	undefined	>=limited	<i>developed</i>	medium
5	*	limited	<i>developed</i>	medium
6	<i>defined</i>	<=limited	<i>developed</i>	medium
7	<i>defined</i>	limited	*	medium
8	<i>defined</i>	>=limited	underdeveloped	medium
9	<i>defined</i>	<i>existent</i>	<i>developed</i>	<i>strong</i>

Table 6 Utility table for External knowledge integration for networked innovation.

	academics and industry integration	dynamics of external network development	External knowledge integration for networked innovation
	73%	27%	
1	nonexistent	*	underdeveloped
2	*	none	underdeveloped
3	<i>existent</i>	>=slow	<i>developed</i>

Table 7 Utility table for Knowledge sharing.

	Explicit knowledge sharing	Tacit knowledge sharing	Embedded knowledge sharing	Knowledge sharing
	32%	37%	32%	
1	weak	weak	*	weak
2	weak	*	weak	weak
3	*	weak	weak	weak
4	weak	>=medium	>=medium	medium
5	<=medium	>=medium	medium	medium
6	*	medium	>=medium	medium
7	medium	*	medium	medium
8	>=medium	<=medium	>=medium	medium
9	medium	>=medium	<=medium	medium
10	>=medium	medium	*	medium
11	>=medium	>=medium	weak	medium
12	>=medium	<i>strong</i>	<i>strong</i>	<i>strong</i>
13	<i>strong</i>	<i>strong</i>	>=medium	<i>strong</i>

Table 8 Utility table for Explicit knowledge sharing.

	systems for decision support	Management culture	ontology	Explicit knowledge sharing
	18%	41%	41%	
1	weak	discouraged	*	weak
2	weak	*	nonexistent	weak

3	*	discouraged	nonexistent	weak
4	weak	<i>motivated</i>	<i>existent</i>	medium
5	>=medium	discouraged	<i>existent</i>	medium
6	>=medium	<i>motivated</i>	nonexistent	medium
7	>=medium	<i>motivated</i>	<i>existent</i>	<i>strong</i>

Table 9 Utility table for Management culture.

	employees behavior	usage of ICT tools for knowledge sharing	Management culture
	50%	50%	
1	discouraged	*	discouraged
2	*	not available	discouraged
3	*	<i>available</i>	<i>motivated</i>

Table 10 Utility table for Tacit knowledge sharing.

	Informal networks and innovation	Social and individual aspects of communication	Organizations role in communication	Tacit knowledge sharing
	40%	30%	30%	
1	weak	unsupported	*	weak
2	weak	*	weak	weak
3	*	unsupported	weak	weak
4	<=medium	>=supported	>=medium	medium
5	medium	*	>=medium	medium
6	>=medium	unsupported	>=medium	medium
7	medium	>=supported	*	medium
8	>=medium	>=supported	weak	medium
9	<i>strong</i>	>=supported	>=medium	<i>strong</i>

Table 11 Utility table for Informal networks and innovation.

	social networks and media	innovation through collaboration	Informal networks and innovation
	43%	57%	
1	some	<=medium	weak
2	*	weak	weak
3	<=existent	<i>strong</i>	medium
4	existent	>=medium	medium
5	<i>highly existent</i>	>=medium	<i>strong</i>

Table 12 Utility table for Social and individual aspects of communication.

	social capital	IT tools for communication	Social and individual aspects of communication
	33%	67%	
1	*	unsupported	unsupported
2	<=existent	>=supported	supported
3	<i>highly existent</i>	>=supported	<i>strongly supported</i>

Table 13 Utility table for Organizations role in communication.

motivation and awareness for sharing practices	communication among members in different teams	organizational culture	Organizations role in communication
24%	24%	52%	
1 weak	unsupported	*	weak
2 weak	*	underdeveloped	weak
3 *	unsupported	underdeveloped	weak
4 weak	>=supported	<i>developed</i>	medium
5 >=medium	unsupported	<i>developed</i>	medium
6 >=medium	>=supported	underdeveloped	medium
7 >=medium	>=supported	<i>developed</i>	<i>strong</i>

Table 14 Utility table for Embedded knowledge sharing.

Knowledge management system	Learning behavior	Embedded knowledge sharing
63%	38%	
1 poor	*	weak
2 <=well defined	weak	weak
3 well defined	medium	medium
4 <i>very well defined</i>	weak	medium
5 >=well defined	<i>strong</i>	<i>strong</i>
6 <i>very well defined</i>	>=medium	<i>strong</i>

Table 15 Utility table for Knowledge management system.

strategy for managing knowledge management system	scalability of KMS	Knowledge management system
50%	50%	
1 non existent	limited to local organizational branch	poor
2 non existent	<i>possible to transfer knowledge to global branch</i>	well defined
3 <i>existent</i>	limited to local organizational branch	well defined
4 <i>existent</i>	<i>possible to transfer knowledge to global branch</i>	<i>very well defined</i>

Table 16 Utility table for Learning behaviour.

learning behavior of employees	learning practices	Learning behaviour
27%	73%	
1 <=medium	individual learning	weak
2 weak	<i>collaborative learning practices</i>	medium
3 <i>strong</i>	individual learning	medium
4 >=medium	<i>collaborative learning practices</i>	<i>strong</i>

Table 17 Utility table for Organization networks.

Inter organizational innovation	External knowledge integration for networked innovation	Organization networks
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	27%	73%	
1	strong boundaries	*	underdeveloped
2	*	underdeveloped	underdeveloped
3	>=limited boundaries	<i>developed</i>	<i>developed</i>

Table 18 Utility table for Inter organizational innovation.

	boundary clusters	digitalization and innovation	Inter organizational innovation
	67%	33%	
1	existent	unsupported	strong boundaries
2	<i>non existent</i>	unsupported	limited boundaries
3	existent	>=supported	limited boundaries
4	<i>non existent</i>	>=supported	<i>no boundaries</i>

Table 19 Utility table for External knowledge integration for networked innovation.

	academics and industry integration	dynamics of external network development	External knowledge integration for networked innovation
	73%	27%	
1	nonexistent	*	underdeveloped
2	*	none	underdeveloped
3	<i>existent</i>	>=slow	<i>developed</i>